Response of Stream Biological Communities to Agricultural Disturbances in the Great Plains

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Slide 1: *Introductory slide.*

Slide 2: *Great Plains Ecoregion (source: North American Commission for Environmental Cooperation).* During the late nineteenth century, the grassland interior of North America was transformed from a veritable wilderness into one of the largest and most productive agricultural regions on Earth. This process wrought fundamental changes in the character of the land and, ultimately, the rivers and creeks that drained the land. Newly plowed soils were exposed to the erosive forces of wind and water, streams received heavy influxes of silt, and a general decline occurred in the more vulnerable native fish and shellfish populations. Further declines in aquatic life accompanied the proliferation and concentration of domestic livestock; the construction of dams, ditches, and levees; the channelization of streams; the loss of riparian woodlands and wetlands; the introduction of chemical fertilizers and biocides; and the advent of center pivot irrigation. Today, few streams in this region have remained unaffected by large-scale agriculture. Nearly all have experienced some change in their original physical structure, hydrology, water quality, and biology as a result of food production practices and policies implemented during the past 150 years.

Slide 3: *Proposed biological integrity categories.* Conceptually, aquatic biological responses to progressive levels of agricultural disturbance may be partitioned into at least six distinctive categories or classes. Class A represents the natural or pre-settlement stream condition and corresponds to the ecological integrity objective of the Clean Water Act. Class B closely approaches this objective by maintaining a high degree of chemical and physical integrity and supporting "a balanced, integrated, adaptive community of organisms having a composition and diversity comparable to that of the natural habitats of the region" (Frey 1977). Class C is measurably degraded with respect to the contemporary reference condition but meets applicable numeric and narrative criteria for the protection of the aquatic life use, as designated in state and tribal water quality standards. Classes D, E, and F are deemed, respectively, partially supportive, non-supportive, and grossly non-supportive of the designated aquatic life use. These last three classes do not comply with the interim goals of the Clean Water Act and represent surface waters subject to listing as biologically impaired systems under section 303(d) of the Act. The remainder of this presentation examines each of these six biological integrity categories in greater detail and concludes by examining the diagnostic and regulatory utility of this conceptual framework using biological data obtained from streams in Kansas.

Slide 4: *Representative class A stream (source: Kansas State Historical Society).* Some indication of the historical character of streams in the Great Plains is provided by the narrative accounts of early nineteenth century explorers, e.g., Lewis and Clark, Zebulon Pike, Stephen Long, Thomas Say, John Fremont, George Sibley. These individuals encountered many streams in the region with shifting sand bottoms, shallow braided channels, wide seasonal fluctuations in flow, and a general paucity of woody riparian vegetation. Other commonly reported features included adjoining riparian wetlands and strong surface water-groundwater connections in the form of springs and seeps. Many creeks and smaller rivers were noted for their transparency and were later found to support populations of a variety of predominately eastern fish and shellfish species, most requiring clear water and comparatively stable stream bottoms. This is a photograph of the South Fork Solomon River, located in the High Plains of northwestern Kansas. It was taken in the early 1890s, a decade or so after the arrival of the first wave of Euro- and Afro-American settlers. It illustrates many of the features attributed to streams in this region by the earlier explorers.

Slide 5: *Another historical view of the above stream (source: Kansas State Historical Society).* This image of the South Fork Solomon River likewise depicts a small stream with gently sloping banks, a sandy substrate, and a shallow, braided channel. Like many other streams in this region, the South Fork would dry up completely or form discontinuous pools along much of its length during extended droughts. However, headwater reaches generally maintained some flow owing to reliable contributions from springs and seeps. Following the return of normal weather and stream flow conditions, recovery of biological populations in intermittent reaches was expedited by the migration and drift of organisms from spring-fed headwaters and other refuges such as beaver dam ponds, deeper pools created by channel irregularities, and distant stream reaches less coupled to the local weather conditions. This capacity for rapid recovery from natural perturbations was one of the original hallmarks of stream biological communities in the Great Plains. However, persistent droughts, lasting for years or decades, did induce compositional shifts in native plant and animal assemblages.

Slide 6: *Larger class A stream (source: Kansas State Historical Society).* With headwaters in the Rocky Mountains, the largest plains rivers (Missouri, Arkansas, Platte) generally attained their peak flows during early summer in response to snowmelt runoff. Much of this water infiltrated the sandy alluviums and underlying aquifers, but a portion returned to the river channels as base flow during drier seasons. These large streams were deceptively swift and maintained an obvious yellow or milky turbidity during periods of normal flow owing primarily to the suspension and transport of fine sand. At lower flows, groundwater intrusion into the river channels effectively minimized silt deposition and sediment compaction, producing a semi-buoyant substrate or easily yielding “quicksand.” Fish and invertebrate species endemic to these rivers possessed morphological and reproductive adaptations to the turbid water, shallow channels, high current velocities, and unstable stream bottoms. This photograph of the Arkansas River was taken in 1872 near Great Bend, Kansas.

Slide 7: *Weathered molluscan shell material.* In the 1850s and 1860s, railroad surveys and related investigations yielded additional information on the aquatic flora and fauna of the Great Plains and generated more accurate maps and the earliest known photographs of many streams.

More detailed biological surveys were initiated in the mid 1870s and continued well into the next century. Although most of these surveys followed the initial onset of intensive agriculture, they documented the occurrence of several freshwater species that would soon be extirpated from specific watersheds or the region as a whole. In many instances, museum fish and shellfish specimens and recent collections of weathered (but identifiable) molluscan shell material have been used to confirm the earlier biological findings. Archeological and paleontological studies conducted in the latter half of the twentieth century have shed additional light on historical and prehistorical stream conditions and aquatic biological communities in the Great Plains.

Slide 8: *Summary of expected biological conditions: class A streams.* By definition, biological communities in class A streams would have lacked truly nonnative plant and animal species. However, many peripheral (predominantly eastern) forms would have been present in these water bodies, especially in the smaller tributaries with permanent flow, clear water, and stable stream bottoms. The western distributional limits for many peripheral forms would have moved back and forth across the face of the plains in response to natural fluctuations in weather and stream flow conditions. Dominant taxa in larger plains streams, characterized by shifting sand bottoms and by wide seasonal and interannual fluctuations in flow, turbidity, and temperature, would have included a number of truly endemic fish and invertebrate species in addition to various widely distributed taxa attaining their greatest population densities in this region.

Slide 9: *Candidate class B stream.* A few isolated creeks and river segments in the central plains have largely escaped the environmental vagaries of intensive agriculture and other modern human disturbances. These so-called reference streams facilitate the study of minimally altered ecological systems and provide convenient benchmarks for gaging the impacts of modern civilization on similar water bodies located in the same geographical area. Systematic attempts to inventory reference streams in the Great Plains have been initiated only recently, but it is clear that the best candidates are restricted to a few smaller water bodies flowing through exceptionally well managed native grasslands. These possess water quality and hydrological characteristics approaching the historical norm, retain nearly all known elements of their original biological communities, and support few exotic species. This is a photograph of Thompson Creek, a small, spring-fed stream draining a native grassland watershed in the Southwestern Tablelands Ecoregion of southern Kansas.

Slide 10: *Another view of the above stream.* This is another recent photograph of Thompson Creek. Note the clarity of the water, the mixed sand-gravel substrate, and the presence of native grasses and forbs along the gently sloping stream banks. The outside bend of the stream has excavated a hollow beneath the adjacent sod, forming an overhanging canopy of soil and living herbaceous vegetation. Such habitats provide shade and shelter for a wide variety of native fish and wildlife. Groves of young trees, such as the one shown in this photograph, are ephemeral features of the landscape in many grassland watersheds owing to the occurrence of wildfires and fires deliberately set for range management purposes. The scattered presence of young trees provides for the maintenance of substantial beaver populations, and the occurrence of woody debris in the stream channel enhances aquatic habitat diversity.

Slide 11: *Larger stream exhibiting some class B attributes.* Larger streams in this region generally have experienced more substantive changes in their biotic and abiotic attributes. Although some pass through essentially intact corridors of native vegetation and superficially resemble the historical condition over restricted reaches, the natural flow regime has been modified dramatically in nearly all such ecosystems. This segment of the North Branch Ninnescah River is located in the Central Great Plains Ecoregion of south-central Kansas. It is characterized by a sandy substrate, a shallow braided channel, and clear water during low and moderate flow conditions. Native grasses and forbs grow to the edge of one of the gently sloping stream banks, and a grove of young cottonwoods has temporarily established itself along the opposite bank. This stream segment has lost some of its original complement of fish and freshwater molluscan species owing to declines in water quality, habitat fragmentation (reservoir construction), and other factors. It also has been populated with a number of nonnative fish species as a result of public and private stocking efforts and unintentional (e.g., bait bucket) introductions. A concerted effort to apply agricultural best management practices upstream of this location has led to recent improvements in water quality and should help facilitate the return of some of the extirpated aquatic species.

Slide 12: *Another larger stream exhibiting some class B attributes.* In some areas of the Great Plains, decades of irrigated crop production have exacted a heavy toll on stream life by lowering groundwater tables, reducing base flows, and transforming formerly perennial water bodies into intermittent or ephemeral systems. This is the Cimarron River as it appears in southwestern Kansas just upstream of the Oklahoma border. Although the Cimarron has experienced major hydrological changes during the past half century, its lower reaches continue to maintain base flow during all but the severest drought conditions. Note the river's sandy substrate, shallow channel, and adjoining, sharply delimited wetland community. This segment is listed as critical habitat for the federally threatened Arkansas River shiner.

Slide 13: *Assorted mussel species.* Historically, over 50 mussel species reached their western distributional limits within the Great Plains. Larger rivers with shifting sand bottoms sometimes supported small populations of these animals in side channels and quiescent backwater regions or in isolated gravelly reaches below disintegrating bedrock outcrops. In contrast, many smaller streams and a few medium sized rivers with gravelly bottoms supported diverse mussel assemblages and dense mussel populations. The survival of these animals in a region of highly variable weather and stream flow was sometimes difficult, and many populations were subject to range regressions during prolonged droughts. Some species were especially sensitive to siltation and among the first animals to disappear from streams following the onset of intensive agriculture.

Slide 14: *Historical versus contemporary distribution of a native bivalve.* Some peripheral mussel species have been eliminated from all (or nearly all) of their original habitats in this region, including streams otherwise regarded as candidate reference systems. The black sandshell, once widely distributed in eastern Kansas, is now represented by only a single known population in the state. At least 11 aquatic molluscan taxa and 22 fish species have been extirpated from Kansas during the past 150 years. An additional 23 aquatic molluscan and 28 fish species are now designated as endangered, threatened, or in need of conservation. Surrounding states have experienced similar declines in their native fish and shellfish fauna.

Slide 15: *Rapid spread of an introduced bivalve species.* Some exotic plant and animal species are now widely distributed in this region. For example, the Asian clam was first reported in Kansas in the early 1980s and is now firmly established at about one-third of the sites included in the KDHE stream biological monitoring network. Even some candidate reference streams in this region support small populations of Asian clam. Other widespread exotic species include watercress, deliberately planted in springs along military, merchant, and migrant trails in the mid nineteenth century, and common carp, released throughout the state in the 1870s for "fisheries enhancement" purposes.

Slide 16: *Summary of expected biological conditions: class B streams.* As indicated previously (slide 3), contemporary reference streams should exhibit a very high degree of chemical, physical, and biological integrity. This stipulation does not preclude the absence of a few historically occurring peripheral species, but it does sharply limit the loss of historically dominant taxa and those species deemed integral to the function and identity of the community as a whole. Similarly, the presence of a few non-indigenous forms in low densities may be acceptable for reference purposes, provided the measured attributes of the biological community are otherwise representative of the wider body of reference systems. Large areas of the Great Plains probably no longer retain true reference streams as a result of decades of intensive agricultural development and other modern human disturbances.

Slide 17: *Representative class C stream.* Although most streams in the Great Plains deviate markedly from the ecoregional reference condition, many meet an important interim goal of the Clean Water Act by complying with established narrative and numeric criteria for the protection of the aquatic life use. This is a photograph of the Republican River as it appears just south of the Kansas/Nebraska border. Significant hydrological changes have accompanied the plowing of the grassland, the construction of several large federal reservoirs, and the ongoing diversion of large amounts of surface water and groundwater for crop irrigation. The curtailment of prairie wildfires has allowed a thin belt of trees to become established along much of the stream course. Agricultural operations in this basin have resulted in detectable pesticide residues and elevated turbidity, nutrient, and fecal coliform bacteria concentrations in the river during all but the lowest flow conditions. These changes in hydrology and water quality have contributed to declines in several historically occurring fish and shellfish species.

Slide 18: *Another representative class C stream.* This is Day Creek, a small tributary of the Cimarron River in southwestern Kansas. The trees on either side of the stream are salt cedar, *Tamarix* sp., a highly invasive exotic species whose initial establishment along a stream course is often attributable to overgrazing. Salt cedar thickets transfer enormous quantities of groundwater to the atmosphere, effectively reducing flow contributions from springs and seeps. Declining stream flows tend to exacerbate water quality problems by concentrating livestock wastes and other contaminants.

Slide 19: *Summary of expected biological conditions: class C streams.* Relative to class B systems, class C streams support a larger proportion of nonnative plant and animal species and fewer native peripheral and regionally endemic species. Although some faunal groups associated with clean water and permanent stream flow may be poorly represented in the biological community (e.g., stoneflies), EPT percent count generally approaches or exceeds 50%, and pennate diatoms continue to dominate the epilithic and episammic algal assemblages. The original functional attributes of the biological community are largely maintained, despite some readily observable shifts in community structure.

Slide 20: *Representative class D stream.* Streams in this biological integrity category are deemed only partially supportive of the designated aquatic life use. Mill Creek, a tributary of the Little Blue River in northeastern Kansas, provides an interesting case in point. The practice of plowing to the very edge of the stream has resulted in extreme silt loadings. The stream banks are now highly unstable in many locations, with large sections washing into the creek during runoff events. Water turbidity levels are chronically elevated, the original bottom substrate has been buried under a thick blanket of silt, and the stream channel has assumed a trench-like configuration in many locations. These developments have contributed to the extirpation of several fish and shellfish species. Contrastingly, some tolerant fish and invertebrate taxa, native and exotic, have seemingly thrived under these degraded conditions.

Slide 21: *Another representative class D stream.* Crooked Creek is one of the larger tributaries of the Cimarron River in southwestern Kansas. Decades of intensive crop irrigation in the upper watershed and the establishment of a dense salt cedar population along the lower stream course have significantly altered the hydrology of this prairie stream. Declines in stream flow (and contaminant dilution capacity) have exacerbated the overall impact of livestock on surface water quality and the condition of the biological community.

Slide 22: *Dense population of Asian clam.* Some exotic species attain their greatest population densities under conditions of moderate nutrient enrichment. This photograph depicts an extremely dense Asian clam population in the Walnut River of southeastern Kansas. During the past century, the Walnut has been deleteriously impacted by a variety of agricultural and nonagricultural factors and has experienced major losses in native biological diversity.

Slide 23: *Summary of expected biological conditions: class D streams.* In terms of biomass and number of individuals, nonnative species frequently dominate biological communities in class D streams. However, midge larvae, oligochaete worms, and other tolerant native forms may attain very high population densities. Few if any native peripheral or regionally endemic species remain in these systems. EPT percent count generally ranges from 30-50 percent, and pennate diatoms are almost completely absent. Owing to the degree of structural change, functional aspects of the biological community (major trophic pathways, nutrient cycling (spiraling) relationships, P/R ratios, etc.) differ significantly from those of higher quality streams.

Slide 24: *Representative class E stream.* The Black Vermillion River in northeastern Kansas historically supported large populations of the ponderous campeloma snail, the black sandshell mussel, and other peripheral molluscan species. Prior to the onset of stream channelization in the 1980s, the reach shown in this photograph supported a narrow gallery forest and a viable stream fishery. Today, the Black Vermillion is characterized by some of the highest silt and pesticide loadings in the state and serves primarily as a drainage canal for the surrounding farmland. The straight objects crossing the snow covered fields in this photograph are not fence rows; rather they are the channelized remnants of small tributaries.

Slide 25: *Another representative class E stream.* This photograph of one of the headwater tributaries of the Delaware River in northeastern Kansas documents a situation that is relatively common in the Great Plains: intensive grazing by cattle has led to the loss of virtually all herbaceous and woody understory vegetation along the stream banks, and the remaining riparian vegetation presents an ineffectual barrier to the runoff of silt, animal wastes, and other contaminants. Not surprisingly, the stream is generally turbid, and the original sand/gravel substrate is buried beneath a layer of silt. The Delaware River and its tributaries historically supported a rich diversity of fish and shellfish. The National Museum of Natural History houses a fine black sandshell specimen (NMNH 523040) obtained from this river system in 1940.

Slide 26: *Summary of expected biological conditions: class E streams.* At this lower level on the biological condition gradient, virtually all native peripheral and regionally endemic species are missing from the aquatic community. Other sensitive groups of organisms are poorly represented (e.g., EPT) or altogether absent (e.g., pennate diatoms). Macrofauna generally are limited to a few hardy exotic species and highly tolerant native taxa. Nuisance algal growths are likely to develop seasonally unless precluded by high turbidity. Energy transfers among trophic levels and nutrient cycling interactions within the biological community are far less efficient than those occurring in higher quality streams.

Slide 27: *Representative class F stream.* This photograph requires no narration.

Slide 28: *Summary of expected biological conditions: class F streams.* In the most organically enriched systems, fish no longer comprise a permanent component of the biological community. Surviving macroinvertebrate life (comprised largely or entirely of air breathing forms such as mosquito larvae) may attain very high population densities owing to limited predation and interspecific competition. Surface (algal and cyanobacteria) scums are likely, especially during the warmer months. Energy transfers and nutrient cycling interactions among the remaining components of the biological community are much less efficient than those occurring in higher quality streams. Particulate organic matter of predominately algal origin is exported downstream in large amounts with minimal biological processing.

Slide 29: *Salt Fork Arkansas River, south-central Kansas.* Now that we've examined each of the six biological integrity categories in some detail, let's consider the potential application of this conceptual framework using biological data from streams in Kansas.

Slide 30: *Ecoregional map of Kansas.* This map depicts the approximate location of long-term biological monitoring sites included in the Kansas (KDHE) stream biological monitoring network. The paucity of sites in the western third of the state reflects the general absence of reliably flowing streams in this region. Crop irrigation has been implicated as a primary factor in the loss of stream base flows over much of western Kansas.

Slide 31: *Distribution of monitoring sites among biological integrity categories.* This graph summarizes lower quartile EPT data from 72 monitoring sites surveyed for five or more years under a seasonally rotating schedule. Delineation thresholds correspond approximately to inflection points on the graph. For 305(b) reporting purposes, four additional macroinvertebrate metrics are considered by KDHE before assigning individual sites to their respective (aggregate) biological condition categories (see slide 32, below). Note that this approach does not readily distinguish between classes B and C near the upper end, or between classes E and F at the lower end, of the biological condition gradient.

Slide 32: *Declines in native mussel assemblages.* Recent assessments of streams in Kansas also have considered documented declines in local freshwater mussel assemblages. This direct biological measure is responsive to a wide variety of environmental stressors and provides an integrated measure of ecological condition over time frames ranging from years to decades (or much longer if consideration is given to the collection and identification of weathered shell material). As shown in this graph, sites retaining 90-100 percent of their pre-settlement mussel species are deemed fully supportive of the aquatic life use, sites retaining 75-89 percent are assigned to the partially supportive category, and sites retaining 0-74 percent are assigned to the non-supportive category. Class B streams generally retain their entire complement of mussel species, although some may lack one or two historically occurring peripheral species (cf., slide 14).

Slide 33: *Closing comments.* **(1)** Most generalizations made during this presentation have been based on biological monitoring data obtained from Kansas and may not apply well to all areas of the Great Plains. **(2)** Non-agricultural stressors also contribute to biological use impairments in many streams in this ecoregion. **(3)** Because short-term fluctuations in rainfall and stream flow may elicit transient changes in the relative abundance of certain fish and aquatic invertebrate species, at least 3-5 years of monitoring data normally are needed in this region to confidently assign streams to their respective biological condition categories.

Slide 34: *Closing comments (continued).* **(4)** Historical narrative accounts and photographs, early biological survey reports, museum fish and shellfish collections, and published archeological studies provide sources of information useful (if not indispensable) in the reconstruction of the pre-settlement baseline condition. **(5)** Classical biological indices (MBI, EPT, IBI, etc.) may not be sensitive enough, by themselves, to reliably identify the remaining reference streams in this ecoregion. Surviving populations of historically occurring key species and indicator taxa should be used to verify the reference condition under such circumstances.

Slide 35: *Closing comments (continued).* **(6)** Contemporary reference streams should retain historically dominant taxa and those species deemed integral to the function and identity of the pre-settlement stream communities. **(7)** The absence of a few historically occurring peripheral species should not automatically preclude the designation of a stream as a reference ecosystem. **(8)** Nonnative species, in low numbers and densities, may be acceptable for reference purposes provided other measured attributes of the biological community are representative of the wider body of reference systems.

Slide 36: *Closing slide.* I would like to thank my colleague, Steve Cringan (shown in photo), for his help in developing this presentation. Additional technical assistance was provided by Mike Butler, Eva Hays, and Steve Haslouer, all of the Kansas Department of Health and Environment.